The Galactic Halo

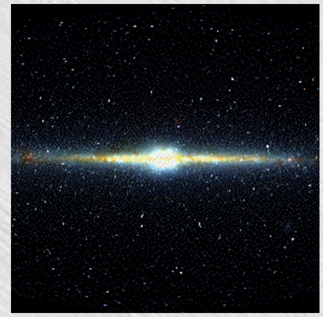
Properties:

- roughly spherical distribution (possibly slight flattening).
- only old stars, with no star formation whatsoever.
- no gas and no dust.
- most recent star formation ended ~10 billion years ago.
- stars are not moving on circular orbits, but on random orbits.
- A lot of substructure; this is an area of active research...

The Galactic Disk

Properties:

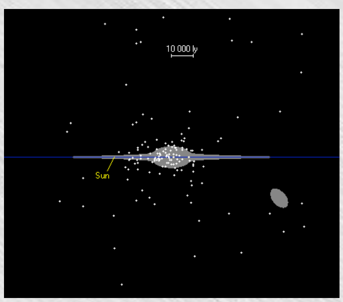
- a thin, flattened disk.
- composed predominantly of young stars, but old stars are also present.
- rich in dust and gas.
- star formation is ongoing.
- stars moving in circular orbits around the Galactic center.



Shapley's Center of the Galaxy

- To find the center of the Galaxy, Shapley measured the distance to each cluster using **RR Lyrae** stars and produced a three dimensional plot of the clusters' positions. The center of the Galaxy was then identified by the average position of the clusters.

- We now know that Shapley's distance to the Galactic center was ~ three times too large because of calibration errors in his derived distances to the cluster, however, his reasoning was impeccable.



Height and Thickness of MW

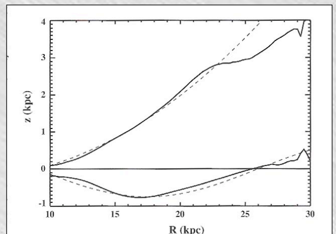


Fig 16.12. Height of the plane of the Milky Way, as determined from 21 cm observations. The solid contours are heights (in kpc) above the plane, and dashed contours are heights below the plane, where the solid lines trace the warp heights in the first and second quadrants (upper) and in the third and fourth (lower). The dotted lines are fits used in modelling. [Butler Burton, Sterrewacht, Leiden University]

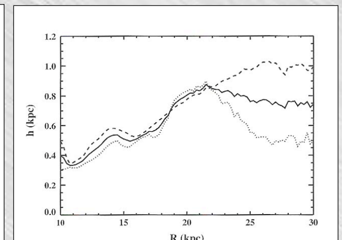
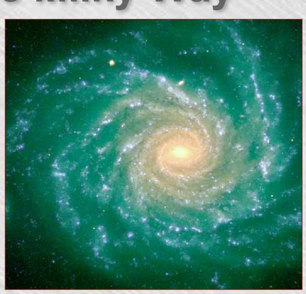


Fig 16.11. Thickness of the plane of the Milky Way as determined from 21 cm observations. The plot shows the layer thickness (measured as a gaussian width), with dotted lines for range $20^\circ < \theta < 160^\circ$, the dashed for $200^\circ < \theta < 340^\circ$, and the solid line the average of both ranges. θ is galactocentric azimuth, where $\theta = 0^\circ$ is the direction $\ell = 0^\circ$. [Butler Burton, Sterrewacht, Leiden University]

Anatomy of the Milky Way

- Our Galaxy is classified a *spiral* because of its prominent luminous spiral arms. The high luminosity of the arms is due to the very bright O and B stars which are often located in open clusters and surrounded by very luminous regions of ionized hydrogen (HII regions) : the bright objects that delineate the spiral arms are called *tracers.*

M39: Open Cluster in Cygnus

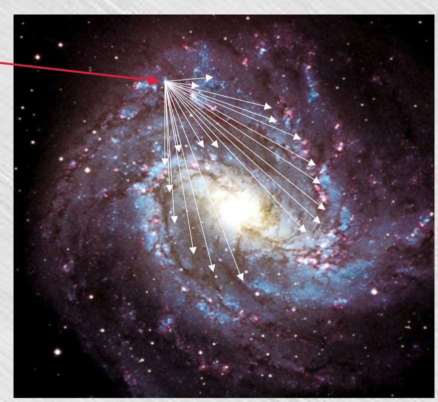


NGC 1232 (D=22 Mpc)

Spiral Arms in the Galaxy M83

- Assume a planet is located here in M83, a galaxy that is similar to the Milky Way.

- *If* we can find the bright **OB associations**, and measure their distances, we can map the arms.



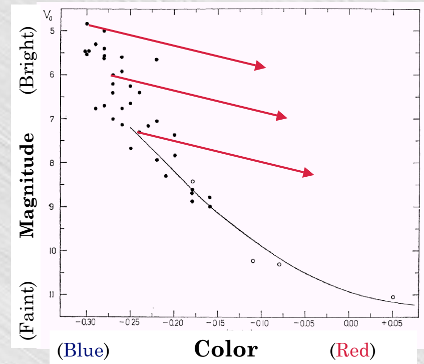
Mapping OB Associations

- During the mid to late 1950's, astronomers (Morgan, Osterbrock) located OB associations, and took spectra of the individual stars.
- Spectroscopic classification and/or H-R diagrams gave astronomers the *luminosities, L,* (actual brightness) of the stars.
- Correcting for reddening, and using the *apparent* brightness, *b*, astronomers could calculate the distances, *d*, to the OB associations.

$$b = \frac{L}{4\pi d^2}$$

Distances for Typical OB Associations

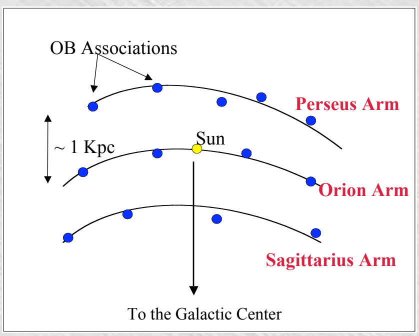
- Imagine moving this OB association to larger and larger distances.
- All of its stars will become fainter and redder, moving along parallel "reddening lines".



Three Spiral Arms Near the Sun

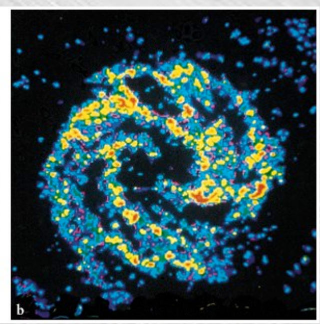
- If we want to map out the orbital motions of stars in the Galactic disk, we need to do three things:

1. Find the OB associations.
2. Measure their radial velocities using spectra and the Doppler Shift.
3. Measure the distances by using their H-R diagrams.



Radio Maps of Other Galaxies Show That Spiral Arms are Traced by HI

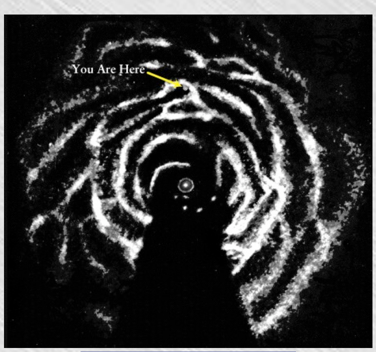
Optical Image



21 cm Radio Image

HI Map of the Galaxy

- In practice, astronomers usually use radio observations of neutral hydrogen (HI) to map out the orbital motions within the disk of the Milky Way.
- Measuring the Doppler Shift of the neutral hydrogen clouds in the disk, astronomers can:
  1. map out the rotation in the disk; and
  2. measure the mass of the Galaxy!



The Milky Way as seen from above, in HI.

Doppler Shift by Differential Rotation

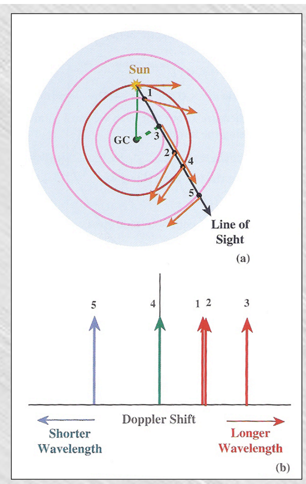
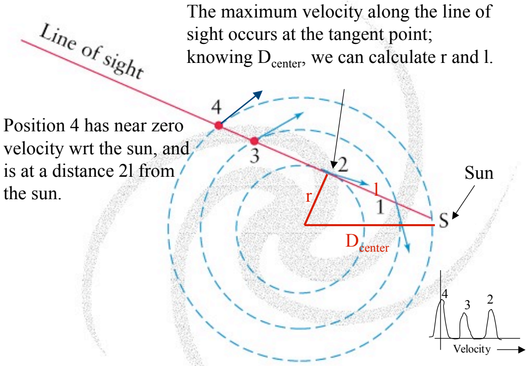


Fig 16.4. Doppler shift produced by galactic differential rotation by material at different locations along a given line of sight. (a) The locations of five test particles in an overhead view. Arrows for each particle indicate the velocity (magnitude and direction). For each particle the Doppler shift will depend on the relative radial velocity of that particle and the Sun. (b) For each particle, the position of the arrow shows the amount of Doppler shift.

HI in the Galaxy: Sizing out the Milky Way

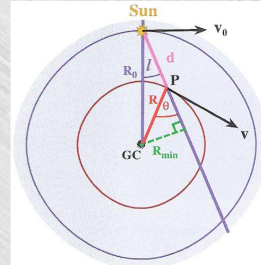
The maximum velocity along the line of sight occurs at the tangent point; knowing D_{center}, we can calculate r and l.

Position 4 has near zero velocity wrt the sun, and is at a distance 2l from the sun.



This method of mapping HI works, *provided* the HI orbits the galaxy with circular velocity.

Fig 16.6. Differential rotation and radial velocities. The sun is a distance R_0 from the galactic center. We observe an object at point P, along a line making an angle ℓ with the line of sight from us to the galactic center. P is a distance R from the galactic center.



- From the figure, we can see the distance of the subcentral point to the galactic centre, R_{min}

$$R_{min} = R_0 \sin \ell$$

- v_{max} is the maximum radial velocity along a given line of sight, we have the angular speed $\Omega(R_{min})$

$$\Omega(R_0 \sin \ell) = (v_{max} / R_0 \sin \ell) + \Omega_0$$

Radial Velocity

- Taking material a distance R from the galactic centre, moving in a circular orbit with speed $v(R)$
- Radial velocity

$$v_r = v(R)\cos(90^\circ - \theta) - v_0 \cos(90^\circ - \ell)$$
$$v_r = R\Omega(R)\sin\theta - R_0\Omega_0 \sin \ell$$

- Eliminate θ using the sine law, and simplify

$$\sin(180^\circ - \theta)/R_0 = \sin \ell / R$$
$$\sin\theta / R_0 = \sin \ell / R$$

- Substitute back into previous equation and factor

$$v_r = \left[\Omega(R) - \Omega_0\right] R_0 \sin \ell$$

Rotation Curve of the Galaxy

- We measure v_r from Doppler shifts and the longitude l for any object and we determine the angular speed Ω

$$\Omega = (v_r / R_0 \sin \ell) + \Omega_0$$

Transverse Velocity

- Relative velocity

$$v_T = R\Omega(R)\cos\theta - R_0\Omega_0 \cos \ell$$

- From the figure we can derive this relationship

$$R_0 \cos \ell = d + R\cos\theta$$
$$R\cos\theta = R_0 \cos \ell - d$$

- Substituting back into previous equation

$$v_T = \left[\Omega(R) - \Omega_0\right] R_0 \cos \ell - \Omega(R) d$$

Rotation in the Galactic Disk

- We find that the disk rotates in two different ways, depending on the distance from the Galactic center:

1. **Inner Parts: Solid-Body Rotation**
   - speed rises with radius.
   - orbital period is roughly constant.

2. **Outer Parts: Differential Rotation**
   - speed is about constant with radius.
   - orbital period increases with radius.